Receive Antenna Diversity and Subset Selection in MIMO Communication Systems

Prof. Shreedhar A. Joshi [1], Dr. Rukmini T S [2], and Dr. Mahesh H M [3]
[1] Assistant Professor, Electronics& Communication Department, SDMCET, Dharwad, India
[2] Professor in Telecommunication Department and Fellow IEEE member, RVCE, Bangalore, India.
[3] Associate Professor & Chairman Applied Electronics Department, Bangalore University, Bangalore, India.
Shreedhar.j@rediffmail.com

***Abstract*— The performance of Multiple-input Multiple-output (MIMO) systems can be improved by employing a larger number of antennas than actually used or selected subset of antennas. Most of the existing antenna selection algorithms assume perfect channel knowledge and optimize criteria such as Shannon's capacity on bit error rates. The proposed work examines Antenna diversity and optimal/ sub optimal receive strategy in antenna selection. The numerical results for BER, Information capacity with SNR are obtained using mat lab**

***Index Terms*— SISO, SIMO, MRC, SNR, BER, SC.**

I. Introduction

Although MIMO technology improves reliability and transmission rates achievable in wireless systems [1–6], the improvement comes at the expense of higher hardware cost. Indeed, every extra transmit/receive antenna requires its own hardware chain (power amplifier, low noise amplifier (LNA), analog to digital (A/D) convertors, etc.). Therefore, cost-effective implementation of MIMO technology remains a major challenge. Antenna subset selection, where transmission/reception is performed through a subset of the available antenna elements, helps in reducing the implementation cost while retaining most of the benefits of MIMO technology. We begin by reviewing some well-known results on maximum ratio combining and receive antenna selection for single-input-multiple-output (SIMO) antenna systems. In this way, only the best set of antennas is used, while the remaining antennas are not employed, thus reducing the number of required RF chains. The proposed technique only selects the subset of transmit or receive antennas based on the Shannon capacity criterion. Antenna selection algorithms that minimize the bit error rate (BER) of linear receivers in spatial multiplexing systems are presented in [7]. In [8], antenna selection algorithms are proposed to minimize the symbol error rate when orthogonal space-time block coding is used in MIMO systems. In [9] a framework is presented to analyze the performance of multiuser diversity (MUD) in multiuser point-to-multipoint (PMP) MIMO systems with antenna selection and average symbol error rate are derived for the multiuser transmit antenna selection with maximal-ratio combining (TAS/MRC) system. The influence of radiation efficiency on diversity gain and MIMO capacity of wireless communications systems is investigated in [10]When the MIMO channel is time-varying, the optimal antenna subset is no longer fixed. To cope with this situation one has to track the time-varying optimal antenna subset. Early work on antenna selection focused on selection in MISO/SIMO systems. This included the hybrid selection/ maximal ratio combining approach in [11]. Recently, there has been increasing interest [12]–[16] in applying antenna subset selection techniques to MIMO links. In [12], the authors present a criterion for selecting antenna subsets that maximize the channel capacity. As shown in [13], antenna selection techniques applied to low-rank channels can increase capacity. A fast selection algorithm based on "water-pouring" type ideas is presented in [14]. In [15], Heath *et al.*, discuss antenna subset selection for spatial multiplexing systems with practical receivers. Antenna selection algorithms/analysis for space–time codes based on exact and statistical channel knowledge may be found in [16]. An Efficient Transmit antenna subset selection with OFDM technique is considered in [17]. In [18] optimal antenna subset selection problem for maximizing the mutual information in a point-to-point MIMO system is considered. The remainder of this paper is organized as follows. In Section 2, the MIMO system model with antenna selection is presented. We also formulate the Receive antenna diversity problem. In Section 3, optimal and sub-optimal selection techniques are analyzed theoretically. In Section 4, several antenna selection criteria are presented, including maximum capacity, minimum bound on error rate and minimum error rate with respect to SNR. In Section 5, Numerical results are addressed. Section 6 contains the conclusions.

II. Signal and channel models

The proposed signal model uses channel matrix approach between the N_T transmit and N_R receive antennas and is assumed to be non-selective, that is, flat fading and linear time invariant. The signal model follows the equation

$$x[K] = \sqrt{\rho}H\,s[k] + n\,[k] \qquad (1)$$

Where $x[k] = [x_1[k] \ldots x_{NR}[k]]^T$ is the $N_R \times 1$ vector corresponding to the signal received at the N_R receivers and sampled at the symbol rate, $s[k] = [s_1[k], \ldots s_{NT}[k]]^T$ Corresponds to the $N_T \times 1$ symbol vector transmitted by the N_T transmit antennas, ρ is the average signal energy per receive antenna and per channel use. $n[k] = [n_1[k], \ldots, n_{NR}[k]]^T$. is the additive white Gaussian noise (AWGN) with variance 1/2

This is the part of Research work for Prof. Shreedhar A Joshi with RV Center for Cognitive Technologies (RVCCT) Bangalore, and Dept of Research in Electronics, KU, India.

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per real dimension and H =[H:,1, . . . ,H:,N_T] is the $N_R \times N_T$ channel matrix, H:,q = [H_1,q, . . . ,$H_{NR,q}$]T , 1 d” q d” N_T , where Hp,q is a scalar channel between the pth receive and the qth transmit antenna. Figure 1 shows different antenna configurations and SIMO, MISO and MISO signal models leads to antenna diversity gains $h_{i,j}$ which represents different gains resulted from various links.

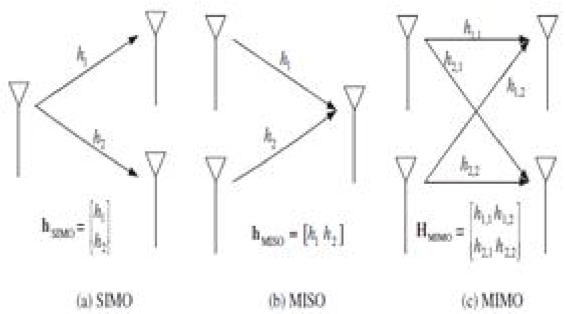

Figure 1. Different Antenna configurations results Receive Diversity

A. Maximum ratio combining with receive diversity

Consider a receive diversity system with N_R receiver antennas. Assuming a single transmit antenna as in the single input multiple output (SIMO) channel of Figure 1, the channel is expressed as

$$h = [\, h_1, h_2, \ldots\ h_{NR}\,]^T \quad (2)$$

for N_R independent Rayleigh fading channels. Let x denote the transmitted signal with the unit variance in the SIMO channel.

$$y = \frac{\sqrt{E_x}}{N_0}\, hx + Z \quad (3)$$

Where Z is zero mean signal Gaussian noise with respect to N_R. The received signals in the different antennas can be combined by various techniques. These combining techniques include selection combining (SC), maximal ratio combining (MRC), and equal gain combing (EGC).

In MRC, all N R branches are combined by the following weighted sum:

$$Y_{MRC} = [\, w_1^{(MRC)}\ w_2^{(MRC)} \ldots\ w_{NR}^{(MRC)}]\, y$$

$$= \sum_{i=1}^{NR} wi^{(MRC)} y_i \quad (4)$$

Where y is the received signal in equation (4) and w_{MRC} is the weight vector. Equation (3), the combined signal can be decomposed into signal and noise parts

$$y = \frac{\sqrt{E_x}}{N_0}\, W_T(MRC)hx + W \quad (5)$$

The average SNR for the MRC is given as

$$\rho_{MRC} = P_s / P_z = E_X / N_0 \frac{|\mathbf{w}_{MRC}^T \mathbf{h}|^2}{\|\mathbf{w}_{MRC}^T\|_2^2}$$

Where term contains upper bounds of rescued SNR for all signals with equal weights. Note that the SNR is maximized at W_{MRC} = h*, which yields

$$\rho_{MRC} = \mathrm{E_x}\|\mathbf{h}\|_2^2/\mathrm{N_0}. \quad (6)$$

In other words, the weight factor of each branch in the above equation must be matched to the corresponding channel for maximal ratio combining (MRC). Equal gain combining (EGC) is a special case of MRC in the sense that all signals from multiple branches are combined with equal weights. In fact, MRC achieves the best performance, maximizing the post-combining SNR. The simulation result shown in section 4 indicates that the performance improves with the number of receiving antennas.

B. MRC versus antenna selection: performance Comparison

The analytical characterization of MRC and antenna selection depends on the receive SNR and antenna selection. With one optimally selected antenna, as a function of the number of receive antennas, the increasing number of receive antenna elements and its performance “gap” between MRC and antenna selection becomes quite substantial. This is hardly surprising since using fewer antennas ought to lead to a loss in average received energy. The real gain of antenna selection in a fading environment is the improved diversity benefit. The inequality states that the SNR through selection is bounded above by the squared channel Frobenius norm (upper bound through MRC) and below by the average power over all antennas. Since both quantities are gamma distributed with parameter N_R the post selection SNR is bounded above and below by two quantities with the same diversity. This implies that receive selection delivers the same diversity as MRC [19, 20].

III. Antenna selection in mimo systems

Assume the presence of M_T transmit antenna elements and M_R receive antenna elements, shown in Figure.2. For a given channel instantiation, N_T out of M_T transmit antenna elements and N_R out of M_R receive antenna elements are selected and used for transmission and reception, respectively. In general, RF modules include low noise amplifier (LNA), frequency down-converter, and analog-to-digital converter (ADC). In an effort to reduce the cost associated with the multiple RF modules, antenna selection techniques can be used to employ a smaller number of RF modules than the number of transmit antennas. Figure illustrates the end-to-end configuration of the antenna selection in which only few RF chains are used to support N_T transmit antennas and even Note that few RF modules are selectively mapped to N_T transmit antennas.

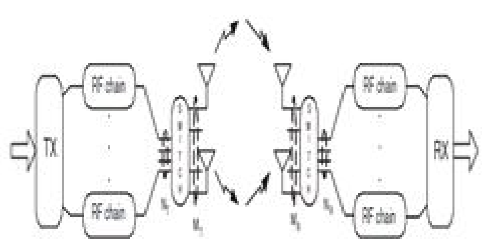

Figure 2. Antenna selections with RF chains and N_T transmit antennas

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A. Optimum Antenna Selection Technique

A set of Q transmit antennas must be selected out of N_T transmit antennas so as to maximize the channel capacity. When the total transmitted power is limited by P, the channel capacity of the system using Q selected transmit antennas is given by

$$\max_{R_{XX},\{p_1,p_2 \ldots p_Q\}} \log_2 \det\left(I_{N_R} + \frac{E_X}{QN_O} H_{\{p_1,p_2 \ldots p_Q\}} H^H_{\{p_1,p_2 \ldots p_Q\}}\right) \text{ bps/Hz} \tag{7}$$

Where Rxx is Q is covariance matrix. If equal power is allocated to all selected transmit antennas, which yields the channel capacity for the given as

$$C_{\{p_1,p_2 \ldots p_Q\}} = \log_2 \det\left(I_{N_R} + \frac{E_X}{QN_O} H_{\{p_1,p_2 \ldots p_Q\}} H^H_{\{p_1,p_2 \ldots p_Q\}}\right) \text{ bps/Hz} \tag{8}$$

The optimal selection of P antennas corresponds to computing Equation (7) for all possible antenna combinations. In order to maximize the system capacity, one must choose the antenna with the highest capacity, that is,

$$\{p_1^{opt}, p_2^{opt} \ldots p_Q^{opt}\} = \arg\max_{\{p_1,p_2,\ldots p_Q\} \in A_Q} C_{\{p_1,p_2,\ldots p_Q\}} \tag{9}$$

Where A_Q represents a set of all possible antenna combinations with Q selected antennas.

B. Sub-optimal Antenna Selection

As mentioned in the previous subsection, optimal antenna selection may involve too much complexity depending on the total number of available transmit antennas. In order to reduce its complexity, we may need to resort to the sub-optimal method. For example, additional antenna can be selected in ascending order of increasing the channel capacity. More specifically, one antenna with the highest capacity is first selected as

$$\begin{aligned} p_1^{subopt} &= \arg\max_{p_i} C_{\{p_i\}} \\ &= \arg\max_{p_i} \log_2 \det\left(I_{N_R} + E_X/QN_O\, H_{\{p_1\}} H^H_{\{p_1\}}\right) \end{aligned} \tag{10}$$

Given the first selected antenna, the second antenna is selected such that the channel capacity is maximized, that is,

$$\begin{aligned} p_1^{subopt} &= \arg\max_{p_2 \neq p_1^{subopt}} C_{\{p_1^{subopt},p_2\}} \\ &= \arg\max_{p_2 \neq p_1^{subopt}} \log_2 \det\left(I_{N_R} + E_X/QN_O\, H_{\{p_1^{subopt},p_2\}} H^H_{\{p_1^{subopt},p_2\}}\right) \end{aligned} \tag{11}$$

After the n^{th} iteration which provides $\{p_1^{subopt}, p_2^{subopt}, \ldots P_n^{subopt}\}$ the capacity with an additional antenna l, assumed as $(n+1)^{th}$ antenna that maximizes the channel capacity in Equation (10), that is, This process continues until all Q antennas are selected (till n +1 = Q) with only one matrix inversion.

$$\begin{aligned} p_1^{subopt} &= \arg\max_{l\{p_i\}} C_l \\ &= \arg\max_{l \notin \{p_1^{subopt} \ldots p_n^{subopt}\}} H_{\{l\}} \left((QN_O/E_X) I_{N_R} + H_{\{p_1^{subopt} \ldots p_n^{subopt}\}} H^H_{\{p_1^{subopt} \ldots p_n^{subopt}\}}\right)^{-1} \end{aligned} \tag{12}$$

IV. Working algorithms

Based on the theoretical assumptions, we have constructed the following algorithms (later converted as m-files). The first algorithm depicts receive diversity technique with MRC under Rayleigh fading channel. The working procedure for the same is as follows:

1. Start.
2. Assume No of frames, No of Packets, set Digital Modulation method as QPSK and SNR limit in db.
3. For first iteration, assume No of Transmit and Receive antennas as $N_T = N_R = 1$.
4. For further iterations, let the Numbers of Tx/Rx antennas are either $N_T=1, N_R=2$ or $N_T=1, N_R=4$ and obtaining a parameter sq_N_T = sqrt (N_T).
5. From SNR in dB, each packet, L, No of frames, obtain Sigma as sigma=sqrt (0.5/(10^(SNR_dB/10))
6. Channel matrix H can be constructed from frame length, N_R
7. For i=1:N_R then autocorrelation factor R is calculated with respect to number of iterations (i) as R (i) = sum (H(i))/sq_NT + sigma*(randn (L_frame,1)
8. The noise vector Z is calculated as Z = Z + R(i).*conj(H(i))
9. Plot SNR Vs BER.
10. Stop.

Similarly the working procedure for optimal antenna selection in MIMO system is as follows;

1. Start.
2. Select transmit/ Receive antennas as $N_T = N_R = 4$; 3.
3. Calculate I=eye (N_R, N_R)
4. Assume SNR range SNR dBs.
5. Assume Q as antenna selection factor (sel_ant) from 1to 4 and determine the length of SNR_dBs.
6. For Individual antenna selection SNR is assumed as SNR_sel_ant = 10 ^ (SNR_dB /10) / Q.
7. Obtain H as H = (randn (N_R,N_T) + j*randn (N_R,N_T))/sqrt (2)
8. If Q > N_T | Q < 1 then Display as 'sel_ant must be between 1 and N_T!'
9. Determine capacity from H (n) factor and Select capacity for maximum iterations.
10. Plot (SNR_dBs, sel_capacity)

The sub-optimal selection working procedure is as follows;

1. Start.
2. Determine Number of antennas to select as sel_ant=2.
3. Assume 0/1 for increasingly/decreasingly ordered Selection
4. Assume Number of Tx / Rx antennas as $N_T=N_R=4$.
5. Obtain, I=eye (N_R, N_R).
6. From SNR range (SNR_dBs)

SNR with selection antenna is given by SNR_dBs = 10 ^ (SNR_dB/10) / sel_ant;

7. Determine selection_antenna_indices upto [1:N_T]
8. Calculate Channel matrix (H) as H = (randn (N_R,N_T)+j*randn(N_R,N_T))/sqrt(2);

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9. If sel_method==0 then, assume increasingly ordered Selection method.
10. For current_sel_ant_number =1:sel_ant obtain H(n) as
log_SH(n) = $\log_2$(real(det (I+SNR_sel_ant*Hn*Hn')))
11. The maximum capacity is depicted as Maximum capacity = max (log_SH);
12. With the help of selected antenna index and Current_del_ant_number determine increasing order Maximum capacity with n+1=Q antennas else repeat the same procedure for decreasingly ordered selection method with n-1=Q and determine maximum capacity
13. Plot SNR_dB Vs capacity.

V. Results and discussions

The effect of symbol errors with SNR in MRC technique is shown in Figure.3. Here SISO (Single Input Single Output) scheme is compared with SIMO (Single Input Multiple Output) scheme. The results clearly indicating improvement in Error propagation.

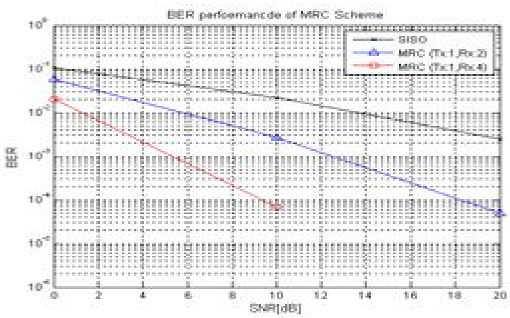

Figure 3. Receive antenna diversity with MRC

We consider the performance of Algorithm II (optimal selection method) which selects the antenna subset maximizing the channel capacity. Here, the transmitter and Receiver antennas are assumed as Tx=Rx= 4 **.** Even considering all possible antenna combinations according to equations mentioned in section III, involving with the enormous complexity, especially when N_T is very large. Figure. 4 shows the channel capacity with antenna selection for NT = 4 and NR = 4 as the number of the selected antennas varies by antenna selection factor (Q) assumed as Q = 1; 2; 3; 4. It is clear that the channel capacity increases in proportion to the number of the selected antennas. When the SNR is less than 10dB, the selection of three antennas is enough to warrant the channel capacity as much as the use of all four antennas.

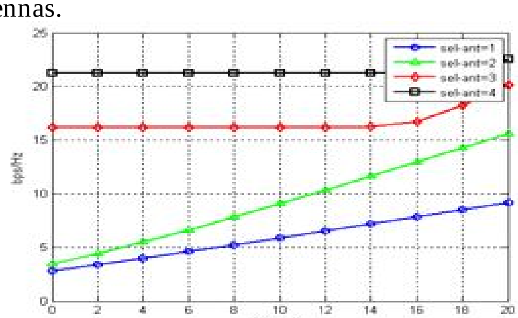

Figure 4. Optimal antenna selection for different Q

In order to reduce the complexity of optimal selection process the sub-optimal antenna selection method, with additional antenna can be selected in ascending order that increases the channel capacity. The performance is evident from Figure.5.

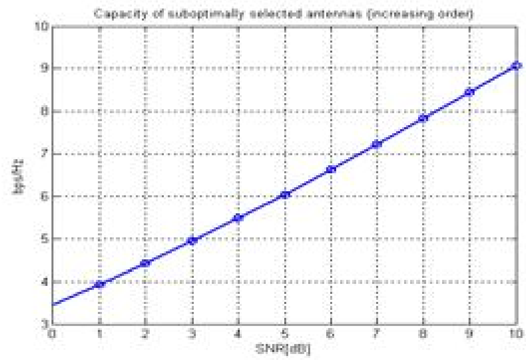

Figure 5. Sub- Optimal antenna selection for different Q

Conclusions

In this paper, we have considered Antenna Diversity method and MIMO antenna selection. MRC scheme improves the information capacity with auto correlation factor. One of the main theoretical conclusions is that selecting a subset of antennas at the transmitter and/or receiver delivers the diversity gain of a "full" system that makes use of all available transmit/receive antennas. This fundamental result extends the well-known observation that selecting a single receive antenna delivers the full diversity gain in a system with a single transmit antenna. Additionally, we extended the framework of diversity versus multiplexing trade-off of MIMO systems to systems with antenna selection. The optimal and Sub-optimal antenna selection techniques provide a possibility of substantial gain increase through increasing and decreasing order by ascending/ descending selection strategies with respect to antennas.

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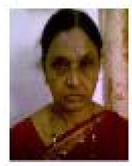
Mr. Shreedhar A Joshi received B.E degree in Electronics and Communication from Karnataka University Dharwad 1994. He has obtained his M. Tech degree in Digital Electronics from VTU Belgaum in 2001. He served as a senior faculty member in various Engineering colleges. Presently he is working as a Assistant Professor in Department of Electronics and communication, SDM College of Engineering Dharwad India. He is persuing PhD in Kuvempu University Shimoga and doing research in MIMO wireless communication field. He has published many international journal papers, IEEE papers Recently He has presented and published a springer LNCIST paper at Kuala Lmpur Malaysia.



Dr.T. S. Rukmini, Professor, Dept of Telecommunication Egineering & P G obtained her Doctoral degree in Microwave Engineering and Antenna Design Microwave Engineering from IISc, Bangalore, Master Degree in P.C.M (P.M.majors) from Bangalore University and Bachelors degree in P.C.M. From Mysore University. Her research interests are Microwave, Antenna and Radars. She is investigating two funded research projects from ISRO & DRDO. She has presented and published papers at national and International conference and Journals. She is also IEEE fellow member.

Dr. Mahesh H. M. received B Sc degree in 1988, M. Sc. degree in 1992 from University of Mysore respectively. He has obtained his Ph.D from University of Mangalore in 2002. From 2002 onwards, worked a post doctoral research Fellow in Queen’s University, Belfast, Ireland. From 2004 onwards, he has worked as a lecturer and coordinator, Department of studies & research in Electronics, Kuvempu University, shimoga. He is presently working as Associate Professor & chairman in the Department of Applied Electronics Science, Bangalore University, Bangalore. His research interests are thin film electronics, molecular electronics, radiation physics,, Wireless Communication etc.

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